REWORKED ACRITARCHS FROM THE TYPE SECTION OF THE ORDOVICIAN CARADOC SERIES, SHROPSHIRE

by ROBERT E. TURNER

ABSTRACT. Thirty-seven acritarch species in the type Caradoc rocks of south Shropshire are recognized as reworked from strata of Tremadoc and Arenig/Llanvirn age, their distribution reflecting an inverted stratigraphy. These microfossils yield valuable palaeoenvironmental data, their excellent preservation indicating a source on, or adjacent to, the Midland Platform; erosion of the relatively unconsolidated parent sediments occurred in a marine environment. Acritarchs were eroded and redeposited as discrete particles and wave and current action are considered the most likely erosive agents. The rate of release of microfossils is linked to a shallowing of the water-body; this resulted in a shift to a high energy environment with storm surges influencing the erosion and redeposition of sedimentary particles.

REWORKING of palynomorphs, the erosion and redeposition of the microfossils within younger sediments, is a problem familiar to most palynologists (Funkhauser 1969; Richardson and Rasul 1978, 1979) and has been discussed by Wilson (1964). Palynomorphs are prone to reworking because of their small size, abundance, and the durable nature of their complex wall. This paper attempts to show that although reworking may present a problem in biostratigraphical studies, it can provide a valuable insight into the depositional environment of the enclosing sediments. Murchison (1839) introduced the term Caradoc to geology when he applied the name 'Caradoc Sandstone' to a group of strata cropping out in the county of Shropshire. The clearest section was said by Murchison (p. 216) to occur in the valley of the River Onny near Horderley. Usage of the term Caradoc has been much restricted by subsequent workers and was given status as a Series by Lapworth (1916) who subdivided it into Groups based on lithology and faunal content. The exposures along the valley of the River Onny are accepted as the type section on historical grounds and these still comprise the best exposed and most complete succession of Caradoc rocks in the district. Since the recent works on the A489 road adjacent to the river, exposure is continuous through much of the sequence and access is better than it has been for many years. Extensive researches have been carried out on the macrofaunas and biostratigraphy of these sediments, a comprehensive review of these works being provided by Hurst (1979*c*). Palaeontological studies have concentrated on the rich shelly faunas, but Jenkins (1967) published some of the earliest microfossil data with his detailed examination of the chitinozoa. Twenty samples were collected from the Onny Valley as part of a larger study of Llandeilo and Caradoc acritarchs from the British Isles. A further thirteen samples were obtained for comparative purposes from north Shropshire in the vicinity of Chatwall Farm (SO 5137 9745, text-fig. 2). All samples were treated with standard laboratory techniques for the recovery of palynomorphs and most yielded abundant, diverse, and well-preserved acritarchs. The majority of samples examined contain numerous acritarchs of undoubted Caradoc age (text-fig. 5); these form the bulk of the acritarch assemblages recovered and will be described elsewhere.

All figured specimens are registered and held in the MPK series of the palynological collections at the Institute of Geological Sciences, Leeds.

[Palaeontology, Vol. 25, Part 1, 1982, pp. 119–143, pls. 15–17.]

AGE OF THE REWORKED MATERIAL

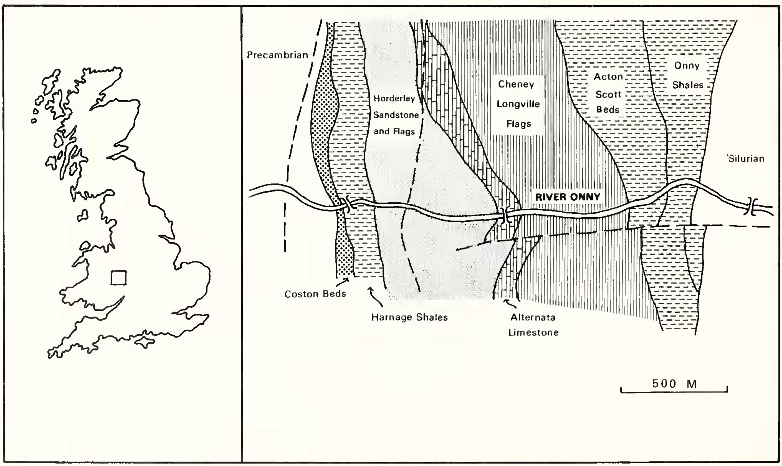
Samples from the Onny Valley contain reworked acritarchs that evidently originated from different sources since, on an age-basis, they fall into three broad categories.

Category 1. Acritarchs of Tremadoc age

Some species recovered can be identified as Tremadoc forms because their known stratigraphical ranges are restricted to strata of this age. Their occurrences here cannot be interpreted as extensions of their ranges because the species concerned remain unknown in strata of Arenig to Llandeilo age (see text-figs. 3, 4).

Category 2. Acritarchs of probable Tremadoc age

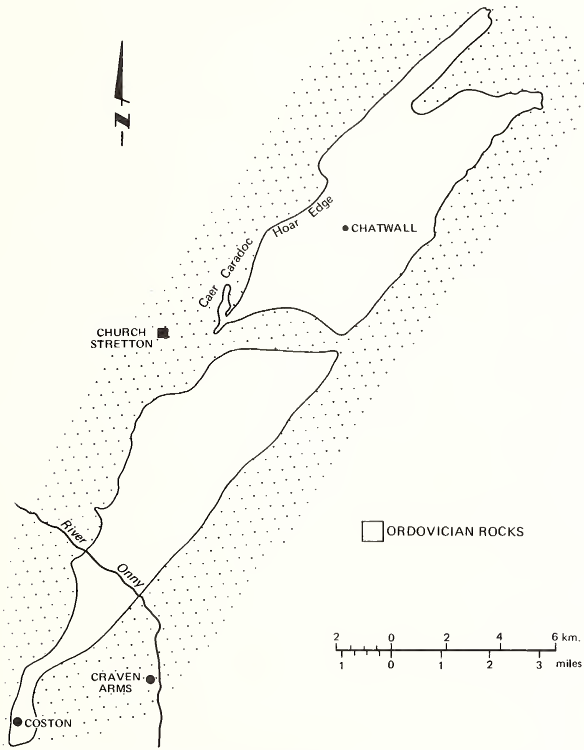
This category consists of taxa that are known both from the Tremadoc and the Arenig/Llanvirn but which, other than this occurrence, have not been recorded from younger strata in the British Isles, or elsewhere (text-figs. 3, 4). That these forms are reworked seems certain, but it is not possible to assign to them a precise stratigraphical age. Despite this, although an Arenig/Llanvirn age is accepted as possible for some of these individuals, it is probable that the majority were derived from rocks of Tremadoc age. This is indicated by the large numbers involved (see text-fig. 3) which suggest derivation from particularly rich pre-existing acritarch assemblages. It is known that parts of the Tremadoc sequence in Great Britain yield abnormally abundant acritarch populations; a rough calculation suggested a figure of 100,000 individuals per gram of rock, for a sample from the *Shumardia pusilla* Zone of the Shineton Shales of Shropshire (Downie 1958, p. 332). These profuse numbers are reflected in the periodic reworking of Tremadoc acritarchs into other parts of the geological column; for example, reworked Tremadoc assemblages have been identified in Devonian rocks in Oxfordshire (Richardson and Rasul 1979) and are known from Llanvirn sediments in north-west England (author's unpublished data). Strata of Tremadoc age are unquestionably the commonest recognized source of reworked acritarchs in the British Isles. In contrast, the work of Booth 1979 (unpublished Ph.D. thesis) and the present author's own unpublished data suggest that in Britain the Arenig/Llanvirn was a period of substantially lower phytoplankton productivity. Thus most of the acritarchs in this group were probably redeposited from sediments of Tremadoc age.



TEXT-FIG. 1. Location and geological setting of the Caradoc type section.

Category 3. Acritarchs of Arenig/Llanvirn age

The species placed in this category have stratigraphical ranges restricted to strata of this age. They are not present in the type Llandeilo of South Wales nor have they been recorded from Llandeilo or younger rocks elsewhere in the world.



TEXT-FIG. 2. Sketch-map of the outcrop of Ordovician rocks around Church Stretton, Shropshire, and the relative positions of exposures at Chatwall and the River Onny.

	SPECIES \ SAMPLE NUMBERS	OV/O/1	OV/O/2	OV/O/4	OV/AS/1	OV/AS/2	OV/UCL/1	OV/LCL/1	OV/LCL/2	OV/A/2	OV/A/1	OV/UHS/1	OV/MHS/1	OV/LHS/2	OV/LHS/1	OV/HS/2	OV/HS/1
TREMADOC FORMS	*Archaeohystrichosphaeridium zalesskyi*							1									4
	Cymatiogalea cristata						1		6	2	2						
	Cymatiogalea velifera							1	4	2	7						1
	Dasydiacrodium palmatilobum										1	2					
	Impluviculus cf. lenticularis	1															
	Saharidia fragile							3		5	2	2					2
	Stelliferidium cortinulum								7	6	5	4	3				
	Stelliferidium stelligerum						1		11	4	4	3	3				
	Timofeevia phosphoritica															1	
	Trichosphaeridium annolovaense							1		1	1	2					2
PROBABLE TREMADOC FORMS	*Acanthodiacrodium/Actinotodissus*							27	41	21	55	19	1		1	1	19
	Micrhystridium diornamentum						1										
	'Polygonium' spp.		2				11	55	82	95	102	45	54	1	2		
	Priscogalea distincta									1							1
	Vulcanisphaera africana								2		2						2
	Vulcanisphaera cirrita								4								1
ARENIG/LLANVIRN FORMS	*Arkonia tenuata*													3			
	Arkonia virgata								2		1		1	1			
	Coryphidium australe					1				1			5	2	1		
	Coryphidium bohemicum			1									1	3	2		
	Coryphidium elegans		1				1										
	Dicrodiacrodium normale															2	
	Dictyotidium ? dentatum				1												
	Frankea breviuscula													1			
	Frankea hamata											3					
	Frankea hamulata															1	
	Frankea longiuscula													1			
	Frankea sartbernardense													2		1	
	Marrocanium simplex													1	1	2	
	Multiplicisphaeridium maroquense										1						
	Multiplicisphaeridium multiradiale	3	1		1				3	1		3	3			2	2
	Multiplicisphaeridium rayii															2	
	Striatotheca frequens					1	1			1	2		1				
	Striatotheca principalis													2		2	
	Striatotheca principalis parva											2			3		1
	Striatotheca quieta		2							1	2	3		4	1	2	1
	?Tunisphaeridium eligmosum										1						
	% Reworked Arenig/Llanvirn species	1.5	2	0.5	1	1	1	–	2.5	2	3.5	11	11	20	8	7	2
	% Reworked Tremadoc species	0.5	–	–	–	–	1	6	14	9.5	11	13	6	–	–	0.5	4.5
	% Reworked probable Tremadoc species	–	1	–	–	–	6	82	64.5	58.5	79.5	64	55	1	3	0.5	11.5
	% Total of reworked species	2	3	0.5	1	1	8	88	81	70	94	88	72	21	11	8	18
	Total number of acritarchs counted	200	200	200	200	200	200	100	200	200	200	100	100	100	100	200	200

TEXT-FIG. 3. The distribution and numerical abundance of reworked acritarchs in samples from the Caradoc type section. The figure for each category of reworked acritarchs identified in every sample is given as a percentage based on a count of 200 specimens, or 100 specimens where acritarchs are sparse.

SPECIES \ PREVIOUS OCCURRENCES	CAMBRIAN	TREMADOC														ARENIG														ARENIG LLANVIRN			LLANVIRN								LLANDEILO		CARADOC
	1 Belgium	2 U.S.S.R.	3 England	4 England	5 England	6 Belgium	7 England	8 Algeria	9 France	10 Sahara,	11 Poland	12 U.S.S.R	13 Belgium	14 France	15 England	16 Bohemia	17 Bohemia	14 France	18 England	13 Belgium	19 Morocco	20 Newfoundland	21 Bohemia	22 Bohemia	23 Bohemia	24 England	25 East Germany	26 England	27 Morocco	28 Morocco	29 Morocco	16 Bohemia	25 East Germany	30 England	22 Bohemia	18 England	31 East Germany	32 France	14 France	13 Belgium	33 U.S.A	14 France	33 U.S.A
'Archaeohystrichosphaeridium' zalesskyi		•	•																																								
Cymatiogalea cristata			•	•	•				•																																		
Cymatiogalea velifera			•	•	•								•																														
Dasydiacrodium palmatilobum			•	•			•																																				
Impluviculus cf. *lenticularis*						•																																					
Saharidia fragile			•	•				•	•																																		
Stelliferidium cortinulum					•			•		•																																	
Stelliferidium stelligerum											•																																
Timofeevia phosphoritica	•		•																																								
Trichosphaeridium annolovaense			•									•																															
Acanthodiacrodium Actinotodissus spp.		•	•	•			•	•	•				•	•		•	•	•	•	•	•	•											•	•							•		•
Micrhystridium diornamentum							•												•																								
'Polygonium' spp.			•				•											•	•			•	•	•											•								
Priscogalea distincta			•		•														•																	•							
Vulcanisphaera africana			•					•	•	•	•		•		•													•															
Vulcanisphaera cirrita															•				•																	•							
Arkonia tenuata																																	•			•							
Arkonia virgata																																	•			•							
Coryphidium australe																													•														
Coryphidium bohemicum																•		•	•																	•							
Coryphidium elegans																			•											•													
Dicrodiacrodium normale																																				•	•					•	
Dictyotidium dentatum																						•			•																		
Frankea breviuscula																										•							•										
Frankea hamata																			•							•							•										
Frankea hamulata																																	•			•							
Frankea longiuscula																																	•			•							
Frankea sarlbernardense																			•	•						•												•	•	•			
Marrocanium simplex																														•													
Multiplicisphaeridium maroquense																			•											•						•							
Multiplicisphaeridium multiradiale																											•																
Multiplicisphaeridium rayii																														•													
Striatotheca frequens																																				•							
Striatotheca principalis																		•									•						•			•							
Striatotheca principalis parva																		•	•							•	•																
Striatotheca quieta																		•													•					•							
?Tunisphaeridium eligmosum																	•															•	•										

TEXT-FIG. 4. Previous records of the reworked taxa identified in the type Caradoc. Locality numbers indicate the following references. 1. Vanguestaine 1978: 2. Timofeev 1959: 3. Rasul and Downie 1974: 4. Downie 1958: 5. Rasul 1974: 6. Martin 1977: 7. Rasul 1979: 8. Combaz 1967: 9. Martin 1973: 10. Deunff 1961: 11. Górka 1967: 12. Timofeev 1966: 13. Martin 1969: 14. Rauscher 1974: 15. Rasul 1976: 16. Vavrdová 1972: 17. Vavrdová 1973: 18. Booth 1979: 19. Cramer and Diez 1977: 20. Dean and Martin 1978: 21. Vavrdová 1966: 22. Vavrdová 1977: 23. Vavrdová 1976: 24. Turner and Wadge 1979: 25. Burmann 1970: 26. unpublished data: 27. Cramer and Diez 1976: 28. Cramer, Allam, Kanes, and Diez 1974: 29. Cramer, Kanes *et al.* 1974: 30. Downie and Soper 1972: 31. Burmann 1968: 32. Paris and Deunff 1970: 33. Loeblich and Tappan 1978.

DESCRIPTIVE PALAEONTOLOGY

Group ACRITARCHA Evitt 1963

The system of informal 'subgroups' proposed by Downie, Evitt, and Sarjeant (1963) has no status under the provisions of the International Code of Botanical Nomenclature (I.C.B.N.). As indicated by Wicander 1974 (p. 11), the introduction of new subgroups which reflect generic names (Staplin, Jansonius, and Pocock, 1965) poses substantial nomenclatural problems. For these reasons it is preferred here not to organize the acritarcha into a suprageneric classification but to simply list them in alphabetical order.

Genus ACANTHODIACRODIUM (Timofeev 1958) Deflandre and Deflandre-Rigaud 1961

The status in the literature of the 'diacrodians' is confused, a situation created when many of the early species described were assigned to invalid genera by Timofeev (1959). The resultant taxonomic confusion was exacerbated by Deflandre and Deflandre-Rigaud (1961) who revised and restricted most of Timofeev's original genera; unfortunately many of their emendations are either invalid or illegitimate under various provisions of the I.C.B.N. and must be rejected. Leoblich and Tappan 1978, discussed this problem (pp. 1236–1238) and created a new genus, *Actinotodissus*. This appears to be differentiated from *Acanthodiacrodium* on minor variations in morphology and has yet to be widely accepted. Considerable numbers of individuals attributable to *Acanthodiacrodium* or possibly to *Actinotodissus* were recorded here but no attempt was made to speciate them. Although the stratigraphical distribution of the 'diacrodians' is not wholly understood, it is clear that in the Tremadoc rocks of Great Britain such forms occur in abundance, while in Arenig and younger rocks they are relatively rare.

Acanthodiacrodium/Actinotodissus spp.

Plate 16, fig. 3

Description. Central vesicle varying in outline from ovate with rounded poles to elongate-subovate. Opposite poles bear similar processes which may be hollow or solid; the central portion of the vesicle is always without processes. Both vesicle and process wall are usually smooth, rarely granulate; the equatorial zone may bear longitudinal striae. No excystment structure recorded.

Genus ARCHAEOHYSTRICHOSPHAERIDIUM Timofeev 1959 ex Loeblich and Tappan 1976

The genus *Archaeohystrichosphaeridium* is technically invalid (see Loeblich and Tappan 1976, p. 303) but many forms originally described under this name have not yet been transferred to other genera. The name is retained here pending transfer of included species to other genera.

Archaeohystrichosphaeridium zalesskyi Timofeev 1959

Description. Central vesicle spherical, smooth, bearing a moderate number (15–25) of smooth, simple, hollow, homomorphic processes which have wide bases tapering to an acuminate distal termination. The process interior communicates freely with the vesicle cavity. No excystment structure recorded. Vesicle diameter 24–33 μm; process length 5–10 μm. Four specimens measured.

Remarks. The spherical forms described here probably belong to the genus *Solisphaeridium* Staplin, Jansonius and Pocock (1965), but transfer should await the examination of *in situ* material.

Genus ARKONIA Burmann 1970
Arkonia tenuata Burmann 1970

Description. Central vesicle hollow, triangular in outline, compressed with each angle bearing a long, hollow, smooth, simple process tapering gradually to an acuminate distal termination. Processes communicate freely with the vesicle cavity and all lie in the same plane as the compression of the central body. The vesicle wall is ornamented with fine, closely spaced striae which are approximately parallel to the vesicle sides; these striae do not extend on to the process wall which is smooth. No excystment structure recorded. Vesicle height 27–32 μm; process length 33–36 μm. Three specimens measured.

Remarks. A. tenuata differs from *A. virgata* Burmann 1970 by having more numerous, more closely spaced, and finer striae ornamenting the vesicle wall.

Arkonia virgata Burmann 1970

Description. Similar to *A. tenuata* in over-all morphology but the vesicle wall is ornamented with fewer, coarse, widely spaced striae. No excystment structure recorded. Vesicle height 28–31 μm; process length 34–39 μm. Four specimens measured.

Genus CORYPHIDIUM Vavrdová 1972
Coryphidium australe Cramer and Diez 1976

Plate 17, fig. 4

Description. Central vesicle hollow, quadrate in outline with rounded corners, strongly compressed. The vesicle wall bears numerous (more than fifty) short, relatively thick processes but is otherwise smooth. Processes tend to be more closely spaced towards the corners of the vesicle and sparse on the central portions. Processes are hollow, smooth, and communicate freely with the vesicle cavity; distal terminations may be capitate, bifurcate, or irregularly bulbous. No excystment structure recorded. Vesicle width 39–42 μm; process length 6–8 μm. Eight specimens measured.

Coryphidium bohemicum Vavrdová 1972

Description. Central vesicle hollow, quadrate in outline with rounded corners, strongly compressed, the sides of the central body may be almost straight or concave. The vesicle wall bears numerous (30–60), short, relatively thick processes which are concentrated towards the corners, with few or none on the central portions of the vesicle. These processes are hollow, smooth, and communicate freely with the vesicle cavity; distal terminations may be flat-topped, bifurcate, multifurcate, capitate, or irregularly bulbous. The vesicle wall also bears well-developed striae which are mostly restricted to those central areas having few processes; these striae are approximately parallel to the vesicle sides around the margins but towards the centre may become strongly concave. No excystment structure recorded. Vesicle width 22–27 μm; process length 3–6 μm. Five specimens measured.

Remarks. Probable occurrences of this species, recorded as 'Indéterminé forme A' in the Caradoc of Ombret, Belgium (Martin, Michot, and Vanguestaine, 1970) are here interpreted as reworked (see also Martin 1977, fig. 14).

Coryphidium elegans Cramer, Allam *et al.* 1974

Description. Central vesicle hollow, quadrate in outline with rounded corners, strongly compressed. The vesicle wall bears numerous (30–60), short, slender processes which tend to be concentrated towards the corners with few or none on the central portions. Processes are smooth, apparently solid, and the distal terminations may be rounded or capitate. The vesicle wall also bears well-developed striae which are most prominent on the central portions but may extend into the corners; these striae are approximately parallel to the vesicle sides but tend to become concave towards the centre. No excystment structure recorded. Vesicle width 20–21 μm; process length 3–5 μm. Two specimens measured.

Genus CYMATIOGALEA (Deunff 1961) Deunff, Górka, and Rauscher 1974
Cymatiogalea cristata (Downie 1958) Deunff, Górka, and Rauscher 1974

Plate 15, fig. 2

Description. Central vesicle spherical to sub-spherical; wall granular, divided into polygonal fields by low sutural ridges which bear smooth, apparently solid processes dividing distally into two to four simple lateral branches; the polygonal areas between sutural ridges lack processes. Excystment is by the development of a large round to sub-polygonal polar opening, the periphery of which also bears processes. The operculum, which is commonly preserved inside the vesicle, is devoid of processes but has a coarse granular ornament. Vesicle diameter 25–31 μm; excystment opening 27–30 μm; process length 15–28 μm. Eight specimens measured.

Cymatiogalea velifera (Downie 1958) Martin 1969

Plate 15, fig. 1

Description. Central vesicle spherical to sub-spherical; wall ornamented with irregular grana and divided into polygonal fields by low sutural ridges that bear processes supporting thin membranes. The processes are smooth, slender, hollow with a solid proximal plug separating the process interior from the vesicle cavity; distally the processes divide into two or four simple lateral branches. Membranes are delicate and transparent although sometimes faint striations or thickenings may be seen. Polygonal areas between sutural ridges lack processes. Excystment is by the development of a large sub-polygonal polar opening the periphery of which also bears processes supporting membranes. The operculum which commonly is preserved inside the vesicle lacks both processes and membranes but has a coarse granular ornament. Vesicle diameter 30–40 μm; excystment opening 26–35 μm; process length 7–12 μm. Ten specimens measured.

Genus DASYDIACRODIUM (Timofeev 1959) Deflandre and Deflandre-Rigaud 1961
Dasydiacrodium palmatilobum Timofeev 1959

Plate 15, fig. 4

Description. Central vesicle ellipsoidal, smooth with rounded poles, one pole bears approximately fifteen simple, smooth, hollow, homomorphic processes which have wide bases and taper rapidly to an acuminate distal termination. The opposite pole bears a larger number (about twenty-five) of much shorter but otherwise similar processes. The intervening equatorial portion of the vesicle is without ornament. The interiors of all processes communicate freely with the vesicle cavity. No excystment structure recorded. Length of long axis 31–33 μm; short axis 26–28 μm; long processes 27–30 μm; short processes 11–14 μm. Three specimens measured.

Genus DICRODIACRODIUM Burmann 1968
Dicrodiacrodium normale Burmann 1968

Plate 17, fig. 5

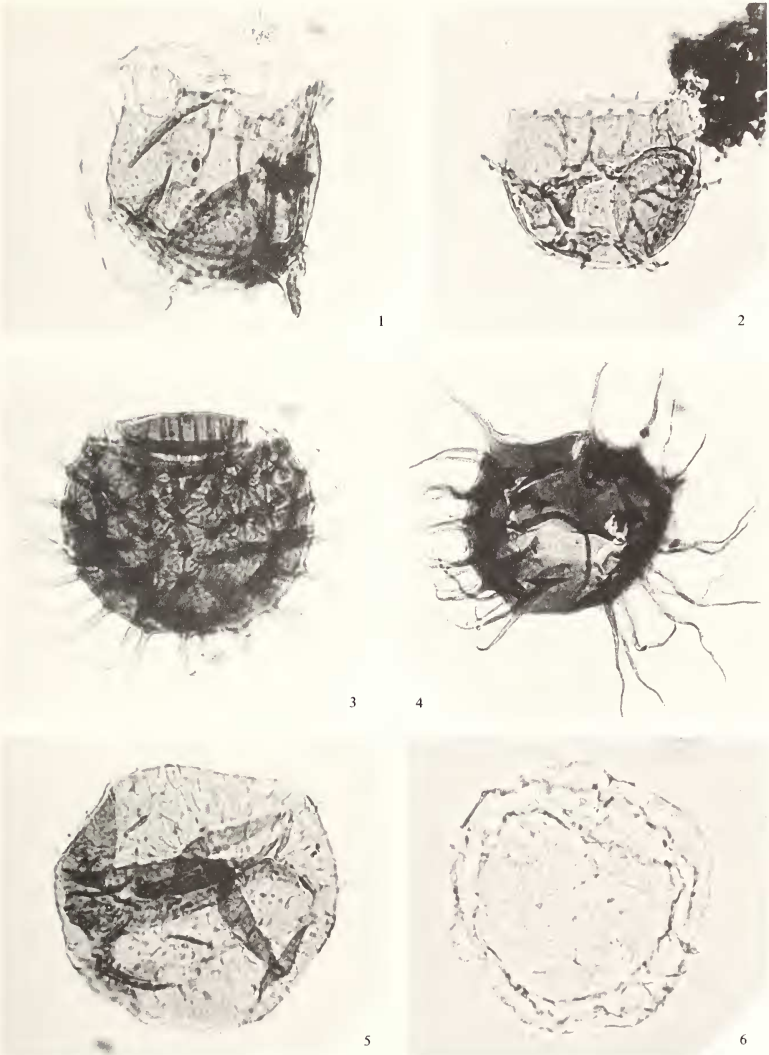
Description. Central vesicle is heteropolar, approximately oval in outline with a broadly rounded antapical pole and a more sharply rounded apical pole. The apical pole bears a single, smooth, hollow, cylindrical process which has a solid proximal plug separating the process interior from the vesicle cavity. Distally this process terminates in five to six short, simple, acuminate branches giving a grapnel-like appearance. The antapical pole bears a dense anastomosing network of fine threadlike processes. The vesicle wall is ornamented with widely spaced longitudinal striae. No excystment structure recorded. Vesicle height 58 μm; vesicle width 33 μm; length of apical process 25 μm. One specimen measured.

EXPLANATION OF PLATE 15

Selected acritarchs of Tremadoc age

All figures × 1200

Fig. 1. *Cymatiogalea velifera* (Downie) Martin. OV/A/2b–5, MPK 2732, Onny Valley, Alternata Limestone. 2. *C. cristata* (Downie) Deunff, Górka and Rauscher. OV/A/2b–1, MPK 2733, Onny Valley, Alternata Limestone. 3. *Stelliferidium stelligerum* Deunff, Górka and Rauscher. OV/A/1a–1, MPK 2734, Onny Valley, Alternata Limestone. 4. *Dasydiacrodium palmatilobum* Timofeev. OV/UHS/1–2, MPK 2735, Onny Valley, Horderley Sandstone. 5. *Trichosphaeridium annolovaense* Timofeev. OV/A/1a–1, MPK 2736, Onny Valley, Alternata Limestone. 6. *Saharidia fragile* (Downie) Combaz. OV/HS/1–1, MPK 2737, Onny Valley, Harnage Shales, phase-contrast.



TURNER, Tremadoc acritarchs

Genus DICTYOTIDIUM (Eisenack 1955) Staplin 1961
Dictyotidium? dentatum (Vavrdová 1976) Dean and Martin 1978

Description. Central vesicle hollow, sub-polygonal in outline. The vesicle surface is divided into a small number of polygonal fields (nine in the one individual recorded) delineated by prominent, smooth, transparent membranes the outer edges of which carry a row of short, capitate, often flat-topped denticles. No excystment structure recorded. Vesicle diameter 45 μm. One specimen measured.

Genus FRANKEA Burmann 1970
Frankea breviuscula Burmann 1970

Description. Central vesicle hollow, smooth, triangular in outline, strongly compressed. Each angle bears a single slender, smooth process of moderate length (up to 70% of vesicle height) that tapers gradually towards the distal end; here it divides into five or six short, simple, acuminate lateral branches that arise in a single plane normal to the compression of the vesicle. The hollow processes all lie in the plane of the central body and communicate freely with the vesicle cavity. No excystment structure recorded. Vesicle height 28 μm; process length 15 μm. One specimen measured.

Frankea hamata Burmann 1970

Description. Similar to *F. breviuscula* in over-all morphology but differing in having shorter processes that always divide distally into two long, smooth, simple, strongly recurved lateral branches with acuminate terminations; these bifurcations occupy the same plane as the compression of the vesicle. No excystment structure recorded. Vesicle height 24–26 μm; process length 13–15 μm; length of lateral branches 11–14 μm. Three specimens measured.

Frankea hamulata Burmann 1970

Description. Similar to *F. breviuscula* in over-all morphology but differing in having short slender processes. No excystment structure recorded. Vesicle height 29 μm; process length 9 μm; length of lateral branches 1–2 μm. One specimen measured.

Frankea longiuscula Burmann 1970

Description. Similar to *F. breviuscula* in over-all morphology but with very long (up to 150% of vesicle height) slender processes. No excystment structure recorded. Vesicle height 41 μm; process length 63 μm; length of lateral branches 5 μm. One specimen measured.

Frankea sartbernardense (Martin 1966) Burmann 1970

Description. Similar to *F. breviuscula* in over-all morphology but with very short stout processes. No excystment structure recorded. Vesicle height 21–24 μm; process length 3–4 μm; length of lateral branches 2–3 μm. Three specimens measured.

Remarks. Records of this species in the Silurian of Belgium (Martin 1969) are interpreted as reworked by the present author.

Genus IMPLUVICULUS (Loeblich and Tappan 1969) Martin 1977
Impluviculus cf. *lenticularis* Martin 1977

Plate 16, fig. 2

Description. Central vesicle hollow, compressed, polygonal in outline, apparently smooth. Each angle bears a slender, flagelliform process which tapers gradually to a closed distal termination; these processes are hollow proximally and communicate freely with the vesicle cavity but may become solid distally. Sometimes two processes may be closely located forming a pair. All processes arise around the margins of the central body and lie in the plane of compression. Vesicle diameter 9 μm; process length 24–28 μm. One specimen measured.

Remarks. Assignment to *I. lenticularis* is not certain since the processes are much longer than those in the type material from the Tremadoc of Brabant, described by Martin (1977).

Genus MARROCANIUM Cramer, Kanes *et al.* 1974
Marrocanium simplex Cramer, Kanes *et al.* 1974

Plate 17, fig. 1

Description. Central vesicle hollow, smooth, quadrate in outline, strongly compressed. Each angle bears a single, smooth, simple process which tapers to a slightly rounded distal termination. The hollow processes lie in the same plane as the central body and communicate freely with the vesicle cavity. Thin, transparent membranes are suspended between the processes; those in a lateral position are wide, stretching out to the process tips while the apical and antipical membranes are seen only immediately adjacent to the vesicle. The membranes appear to be smooth and are fragile. No excystment structure recorded. Vesicle length 30 μm; process length 25 μm. Three specimens measured.

Remarks. The transparent membranes recorded here possibly envelop the entire central body, thus forming a delicate periderm rather than being simple, single-layer structures as described by Cramer, Kanes, Diez and Christopher (1974). More data are required to determine this point.

Genus MICRHYSTRIDIUM (Deflandre 1937) Downie and Sarjeant 1963
Micrhystridium diornamentum Rasul 1979

Description. Central vesicle spherical, bearing two types of process. Some processes are long, hollow, relatively few (5-10), simple, smooth, and taper gradually to a simple acuminate distal termination. The remaining processes are much more numerous (probably more than 50), short, closely spaced, smooth, apparently solid and hair-like. No excystment structure recorded. Vesicle diameter 16 μm; process length 13 μm and 3 μm. One specimen measured.

Remarks. This species, originally described from the Tremadoc of England has subsequently been recorded from the Arenig/Llanvirn of North Wales (Booth 1979, p. 127; as *M. robustum* in part).

Genus MULTIPLICISPHAERIDIUM (Staplin 1961) Eisenack, Cramer, and Diez 1976
Multiplicisphaeridium maroquense Cramer, Allam *et al.* 1974

Description. Central vesicle hollow, smooth, polygonal in outline, formed from the merging of process bases. Processes are long, smooth, broad, and widen rapidly proximally; they divide distally in a characteristic manner with first- and second-order lateral branches the tips of which recurve sharply to give a loosely coiled appearance. Processes are hollow and communicate freely with the vesicle cavity. No excystment structure recorded. Vesicle diameter 29 μm; process length 22 μm. One specimen measured.

Multiplicisphaeridium multiradiale (Burmann 1970) Eisenack, Cramer, and Diez 1976

Plate 17, fig. 2

Description. Central vesicle hollow, smooth, polygonal in outline, formed from the merging of process bases. The processes are long, smooth, broad, and widen rapidly proximally; they divide distally by simple bifurcation up to the third order, forming slender acuminate lateral branches. The processes, varying in number from five to seven, are hollow and communicate freely with the vesicle cavity. No excystment structure recorded. Vesicle diameter 22–27 μm; process length 14–17 μm. Ten specimens measured.

Remarks. This species resembles *M. maroquense* but is distinguished by the third-order branching and the lack of sharply recurved distal tips to the process branches.

Multiplicisphaeridium rayii Cramer, Allam *et al.* 1974

Description. Central vesicle hollow, smooth, polygonal in outline, formed from the merging of process bases. The processes are long, smooth, broad and widen rapidly proximally; they divide distally into four or five digitate, generally straight, dagger-like branches with rare second-order branching. Processes are hollow and communicate freely with the vesicle cavity. No excystment structure recorded. Vesicle diameter 38 μm; process length 44 μm. One specimen measured.

Genus POLYGONIUM Vavrdová 1966
'*Polygonium*' spp.

Plate 16, figs. 5, 6

Description. Central vesicle hollow, polygonal to sub-polygonal, bearing numerous, long, hollow, simple processes which communicate freely with the vesicle cavity and have acuminate distal terminations. Processes may have a consistent concentric arrangement or may be apparently distributed at random. Vesicle wall smooth, process wall smooth or rarely granular. Processes always have wide bases which thin rapidly to a slender stem, tapering gradually to the distal tip. No excystment structure recorded. Vesicle diameter 26–35 μm; process length 15–20 μm. Fifty specimens measured.

Remarks. The acritarchs included here under the name '*Polygonium*' embrace a wider variety of forms than is circumscribed by the genus *Polygonium* Vavrdová 1966. This taxon was considered by its author to be distinguished by always having processes arranged in a consistent concentric manner (Vavrdová 1966, p. 413). Some individuals showing this feature were recorded here (Pl. 16, fig. 6) but most specimens, otherwise indistinguishable, exhibit an apparently random process arrangement (Pl. 16, fig. 5). These forms constitute a taxonomic problem since, although they are abundant in Tremadoc to Llanvirn strata, no valid generic name has yet been proposed for them. The term '*Polygonium*' is used here to denote forms with both concentrically and non-concentrically arranged processes.

Genus PRISCOGALEA Deunff 1961
Priscogalea distincta Rasul 1974

Plate 16, fig. 4

Description. Central vesicle spherical to sub-spherical, bearing about fifty processes which appear to be distributed irregularly over the surface. Processes are smooth, solid, and taper towards the distal ends where they are usually multifurcate; a few bifurcate or simple processes may be present. The vesicle wall is ornamented with faint striae which radiate out from each process base. Excystment is by the development of a large polygonal to sub-polygonal polar opening, the periphery of which also bears processes. The operculum is smooth and without processes. Vesicle diameter 30–33 μm; excystment opening 15–16 μm; process length 6–8 μm. Two specimens measured.

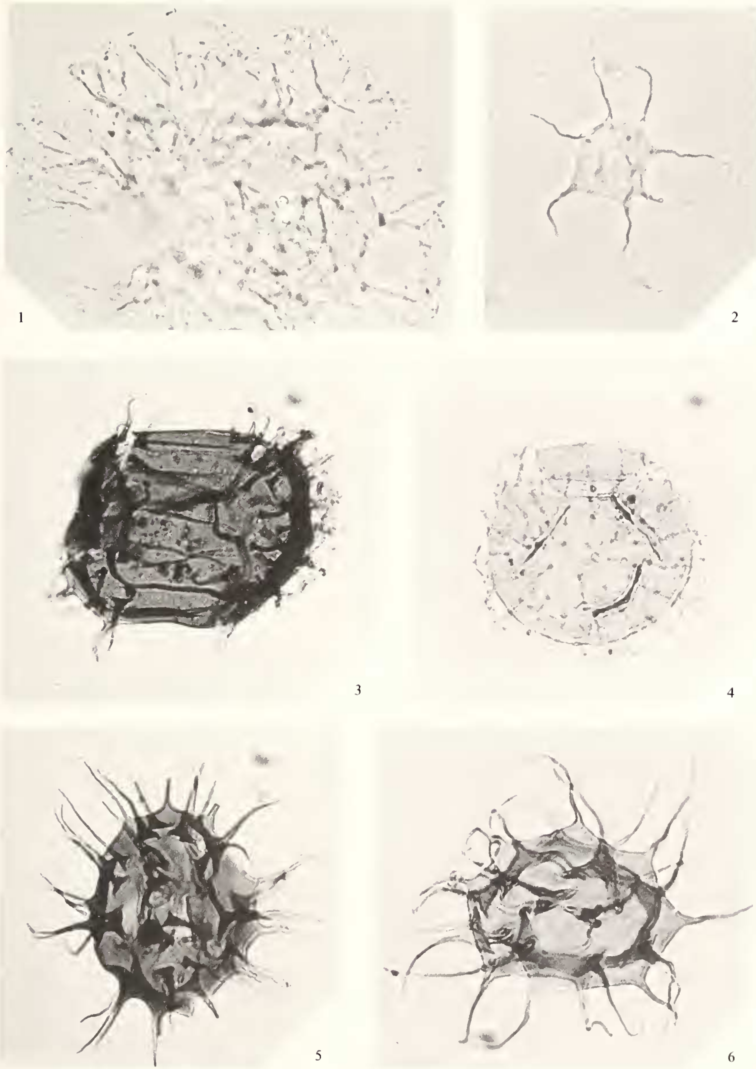
Remarks. The striate vesicle wall justifies the transfer of this species to the genus *Stelliferidium*, but this should await examination of *in situ* material. This species, previously known only from the Tremadoc, has been recorded from the Arenig and Llanvirn of Britain (Booth 1979, pp. 173, 322).

EXPLANATION OF PLATE 16

Selected acritarchs of probable Tremadoc age

All figures × 1200

Fig. 1. *Vulcanisphaera cirrita* Rasul. OV/HS/1–1, MPK 2738, Onny Valley, Harnage Shales, phase-contrast. 2. *Impluviculus* cf. *lenticularis* Martin. OV/O/1–7, MPK 2739, Onny Valley, Onny Shales, phase-contrast. 3. *Acanthodiacrodium*/*Actinotodissus* sp. OV/UHS/1–1, MPK 2740, Onny Valley, Horderley Sandstone. 4. *Priscogalea distincta* Rasul. OV/A/2b–5, MPK 2741, Onny Valley, Alternata Limestone. 5–6. '*Polygonium*' spp. 5. OV/A/1a–1, MPK 2742. 6. OV/A/1a–1, MPK 2743, both from the Alternata Limestone of the Onny Valley.



TURNER, probable Tremadoc acritarchs

Genus SAHARIDIA Combaz 1967
Saharidia fragile (Downie 1958) Combaz 1967

Plate 15, fig. 6

Description. Central vesicle circular in outline, wall thin ($< 0{\cdot}5\ \mu m$), fragile, and ornamented with irregularly sized and spaced grana. Concentric folds are developed in the wall adjacent to the periphery. Excystment is by the development of a small central pylome but often such openings are not apparent. Vesicle diameter 35–70 μm; pylome diameter 9–15 μm. Ten specimens measured.

Genus STELLIFERIDIUM Deunff, Górka, and Rauscher 1974
Stelliferidium cortinulum (Deunff 1961) Deunff, Górka, and Rauscher 1974

Description. Central vesicle spherical to sub-spherical; the wall is thick (1–2 μm) and bears 15–20 smooth processes which appear to be distributed irregularly over the vesicle; these processes are hollow with a solid proximal plug separating the process interior from the vesicle cavity; from the base they taper gradually to a bifurcate or multifurcate distal termination. The vesicle wall is ornamented with faint striae which radiate out from the base of each process. Excystment is by the development of a large circular to sub-polygonal polar opening, the periphery of which always lacks processes. The operculum is smooth and is also without processes. Vesicle diameter 29–36 μm; excystment opening 15–23 μm; process length 5–9 μm. Fifteen specimens measured.

Stelliferidium stelligerum Deunff, Górka, and Rauscher 1974

Plate 15, fig. 3

Description. Central vesicle spherical to sub-spherical, thick-walled (1–2 μm), and bears about sixty processes which appear to be distributed irregularly over the surface. Processes are hollow with a solid proximal plug separating the process interior from the vesicle cavity; they are smooth and taper gradually to a simple acuminate or bifurcate distal termination. Processes tend to be longest at the antapex becoming progressively shorter towards the polar opening. Excystment is by the development of a large, circular to sub-circular opening, the periphery of which bears short, generally bifurcating processes. The operculum, which is commonly preserved *in situ*, is granular and without processes. The vesicle wall is ornamented with thick prominent striae that radiate out from each process base. Vesicle diameter 31–37 μm; excystment opening 18–21 μm; process length 11–15 μm. Fifteen specimens measured.

Genus STRIATOTHECA Burmann 1970
Striatotheca frequens Burmann 1970

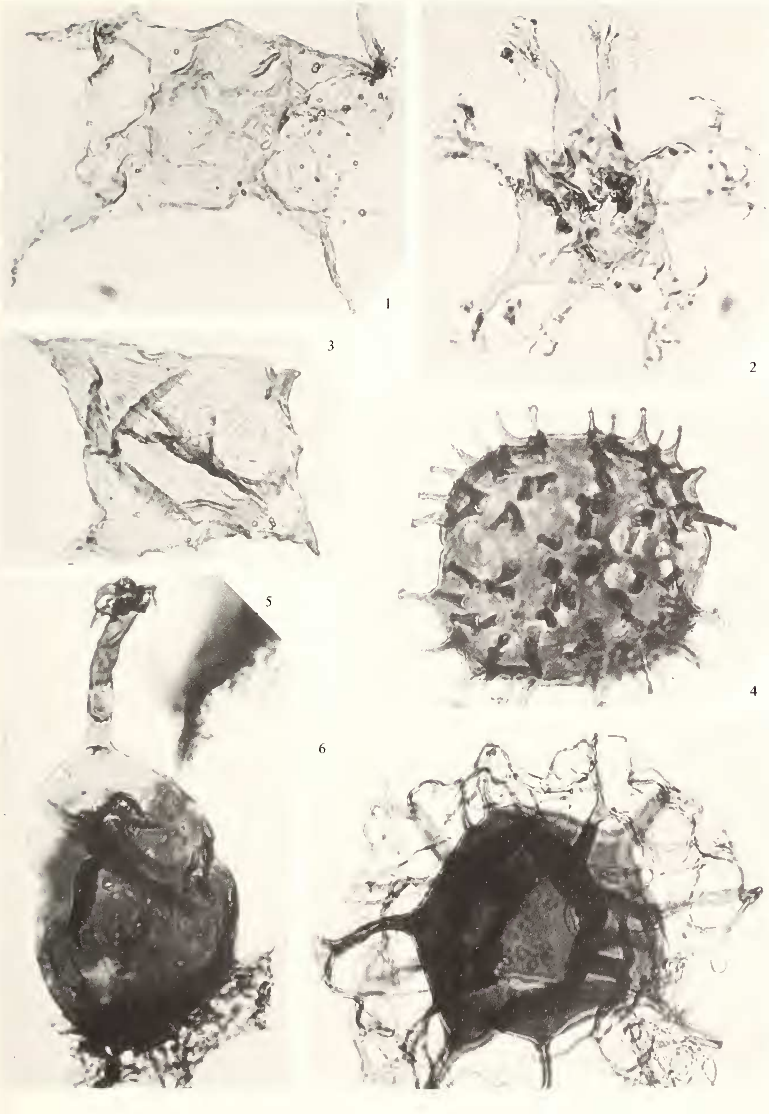
Description. Central vesicle hollow, quadrate in outline, strongly compressed. Each angle bears a single long, broad, simple process which tapers gradually to a generally rounded distal termination. The hollow processes lie in the same plane as the central body and are in free communication with the vesicle cavity. The vesicle wall is ornamented with fine striae that are approximately parallel to the vesicle margins around the periphery but become concave towards the centre; these striae pass on to the processes but die away distally. No excystment structure recorded. Dimensions of central vesicle 33–37 $\mu m \times 31$–36 μm; process length 10–16 μm. Five specimens measured.

EXPLANATION OF PLATE 17

Selected acritarchs of Arenig/Llanvirn age

All figures $\times 1200$

Fig. 1. *Marrocanium simplex* Cramer, Kanes *et al.* NS/4–4, MPK 2744, Chatwall, Harnage Shales. 2. *Multiplicisphaeridium multiradiale* (Burmann) Eisenack *et al.* OV/A/2b–5, MPK 2745, Onny Valley, Alternata Limestone. 3. *Striatotheca quieta* (Martin) Rauscher. NS/4–4, MPK 2746, Chatwall, Harnage Shales. 4. *Coryphidium australe* Cramer and Diez. OV/MHS/1–3, MPK 2747, Onny Valley, Horderley Sandstone. 5. *Dicrodiacrodium normale* Burmann. NS/4–1, MPK 2748, Chatwall, Harnage Shales. 6. *Tunisphaeridium eligmosum* Vavrdová? OV/A/1b–1, MPK 2749, Onny Valley, Alternata Limestone.



TURNER, Areniq/Llanvirn acritarchs

Striatotheca principalis Burmann 1970

Description. Similar to *S. frequens* in over-all morphology but is larger, has long, slender processes with acuminate distal terminations and bears a vesicle ornament of coarse, widely spaced striae. No excystment structure recorded. Vesicle dimensions 40–44 μm × 36–38 μm; process length 20–31 μm. Four specimens measured.

Striatotheca principalis var. *parva* Burmann 1970

Description. Similar to *S. principalis* in over-all morphology, this variety is distinguished by its much smaller size. It differs from *S. frequens* in having slender processes with acuminate distal terminations, and a vesicle ornament of coarse, widely spaced striae. No excystment structure recorded. Vesicle dimensions 27–31 μm × 20–23 μm; process length 15–20 μm. Five specimens measured.

Striatotheca quieta (Martin 1969) Rauscher 1974

Plate 17, fig. 3

Description. Central vesicle hollow, quadrate in outline, strongly compressed; each angle bears an extremely short, simple process which tapers to a rounded distal termination. The hollow processes lie in the same plane as the central body and communicate freely with the vesicle cavity. The vesicle wall is ornamented with fine, closely spaced striae which are approximately parallel to the vesicle margins around the periphery but become concave towards the centre; these striations continue on to the process wall almost out to the distal tip. No excystment structure recorded. Vesicle dimensions 29–32 μm × 33–35 μm; process length 3–5 μm. Twelve specimens measured.

Remarks. Records of this species (as *Veryhachium quietum*) from the Silurian of Belgium (Martin 1969) are interpreted by the present author as reworked.

Genus TIMOFEEVIA Vanguestaine 1978
Timofeevia phosphoritica Vanguestaine 1978

Description. Central vesicle spherical to sub-spherical, wall smooth, divided by raised ridges into about twenty polygonal fields; the junctions of the ridges bear smooth processes which taper gently to a bifurcate or multifurcate distal termination. No excystment structure recorded. Vesicle diameter 32 μm; process length 9–11 μm; diameter of polygonal fields 9–11 μm. One specimen measured.

Genus TRICHOSPHAERIDIUM Timofeev 1966
Trichosphaeridium annolovaense Timofeev 1966

Plate 15, fig. 5

Description. Central vesicle spherical to sub-spherical but always compressed, wall smooth, moderately thick (about 1 μm) with compression folds developed. The vesicle bears more than 100 short, solid, smooth, simple hairlike processes whose distal terminations may be evexate or acuminate. No excystment structure recorded. Vesicle diameter 42–49 μm; process length 3–4 μm. Six specimens measured.

Genus TUNISPHAERIDIUM Deunff and Evitt 1968
Tunisphaeridium eligmosum Vavrdová? 1973

Plate 17, fig. 6

Description. Central vesicle hollow, sub-polygonal in outline, wall smooth, bearing 15–20, long, cylindrical, smooth processes which widen proximally and divide distally by means of simple bifurcation up to the fifth order; the distal terminations of these branches are long, slender, curved, and sometimes appear to join those of adjacent processes forming an anastomosing network of fine filaments. Processes are hollow and communicate freely with the vesicle cavity. No excystment structure recorded. Vesicle diameter 36 μm; process length 28 μm. One specimen measured.

Remarks. The specific assignment is not certain since the branching pattern of *T. eligmosum* is described by Vavrdová as palmate rather than bifurcate as recorded here.

Genus VULCANISPHAERA (Deunff 1961) Rasul 1976
Vulcanisphaera africana Deunff 1961

Description. Central vesicle spherical to sub-spherical, wall smooth or granular, bearing 50–100 processes which arise from hollow conical projections having a solid tip; normally three processes arise from a common base in this way, more rarely two or four. Processes are slender and taper gradually to a bifurcate distal termination. No excystment structure recorded. Vesicle diameter 32–49 μm, process length 10–14 μm. Three specimens measured.

Remarks. The distal bifurcations are extremely fine and delicate and are often broken off giving the appearance of a simple acuminate termination. Published records of this species are restricted to strata of Tremadoc age; the present author has identified the taxon in assemblages from Britain which on their palynological content are of probable Arenig age (unpublished data). It is thus possible that this form ranges above the top of the Tremadoc.

Vulcanisphaera cirrita Rasul 1976

Plate 16, fig. 1

Description. Central vesicle spherical to sub-spherical with 50–100 processes arising from hollow projections which have a solid tip. The number of processes sharing a common base in this way varies from two to five. Processes are slender and taper only slightly towards the distal tip where they branch into numerous delicate thread-like branches. The branches of adjacent process groups may unite to form a complex anastomosing network of fine filaments. No excystment structure recorded. Vesicle diameter 37–48 μm; process length 9–11 μm. Three specimens measured.

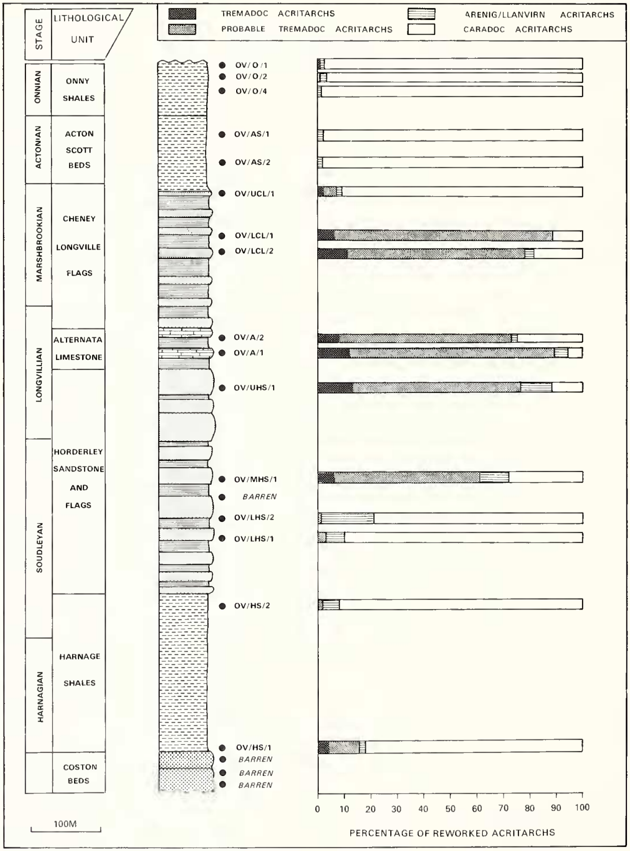
Remarks. Originally described from the Tremadoc of Shropshire, this species has been subsequently recorded from the Arenig/Lower Llanvirn of North Wales (Booth 1979, p. 190).

DISTRIBUTION OF THE REWORKED MATERIAL

The over-all pattern of reworking within the Onny Valley section is shown in text-fig. 5. Reworked acritarchs first appear in the Harnage Shales which represent the onset of fine-grained sedimentation. These acritarchs include species of both Tremadoc and Arenig/Llanvirn age, indicating that strata of both ages were being eroded to supply sediment to the shelf during early Caradoc time. Towards the top of the Harnage Shales and in the lower Horderley Sandstones, Arenig/Llanvirn forms dominate the reworked portions of the assemblages; only minor elements of probable Tremadoc age are present. A possible explanation of this is that widespread erosion of Arenig/Llanvirn sediments was occurring but that only a small area of Tremadoc rock was exposed. From the base of the Harnage Shales up to the middle Horderley Sandstone, reworked acritarchs consistently comprise 10–20% of the total assemblages. Above this level the proportion of reworked specimens in the sediments increases greatly to as much as 70%. This large and sudden increase in reworking is associated with an increase in the percentages of both Tremadoc and probable Tremadoc forms present. The simultaneous increase in the abundance of these two Categories tends to substantiate the Tremadoc age suggested for most individuals placed in Category 2. A high percentage of reworked acritarchs is evident until the upper part of the Cheney Longville Flags, always with taxa of Tremadoc and probable Tremadoc age predominating. The maximum level of reworking occurs in the Alternata Limestone, where up to 94% of the acritarchs are derived, the contemporaneous Caradoc forms being swamped out. The percentage of Arenig/Llanvirn forms fluctuates throughout the middle of the Caradoc sequence but is always small (text-fig. 5). The large numbers of reworked acritarchs of Categories 1 and 2 that are present from the middle Horderley Sandstone through to the upper Cheney Longville Flags suggest that an acritarch-rich source rock of Tremadoc age was extensively breached and continued to be eroded over a substantial period of time.

In the lower Acton Scott Beds reworked acritarchs constitute a mere 1 or 2% of the total assemblage and remain at this much-reduced level up to the top of the succession. This reduction in reworking coincides with a return to a low-energy mudstone environment.

If the majority of individuals placed in Category 2 are accepted as having originated in the Tremadoc then an interesting pattern to the reworking emerges (text-fig. 5). The distribution of taxa is essentially inverted, reflecting successive erosion of progressively older source sediments during Caradoc time. It should be noted that this pattern is modified by the relative abundance of Tremadoc forms at the base of the Harnage Shales. As discussed above, this clearly indicates early erosion of a Tremadoc source rock; however, the paucity of Tremadoc acritarchs in the overlying Harnage Shales



TEXT-FIG. 5. Showing the stratigraphical distribution of samples from the Caradoc type section together with the ages and percentages of the reworked acritarchs recorded from each horizon.

and Horderley Sandstone shows that reworking from this source was subsequently suppressed although not eliminated. Any explanation of this diminution in erosion of Tremadoc sediments would be purely conjectural at present. An inversion of this type, with younger material redeposited in the lower horizons and older forms appearing in the overlying strata, would be expected where relatively undisturbed sediments were being eroded and quickly laid down again. It may be assumed that the rocks discussed here would have been little altered by Caradoc time since the Ordovician was a period of tectonic quiescence in this region (Earp and Hains 1971, p. 89).

Samples from the lower Caradoc of the Chatwall district (text-fig. 2) contain abundant reworked acritarchs of Arenig/Llanvirn age with rare Tremadoc and probable Tremadoc forms, a distribution similar to that in the type section. Since the Caradoc sequence is much less complete at Chatwall and acritarchs are rare above the Harnage Shales, these occurrences are not discussed in detail here but they demonstrate that the reworking is not a local phenomenon restricted to the Onny Valley.

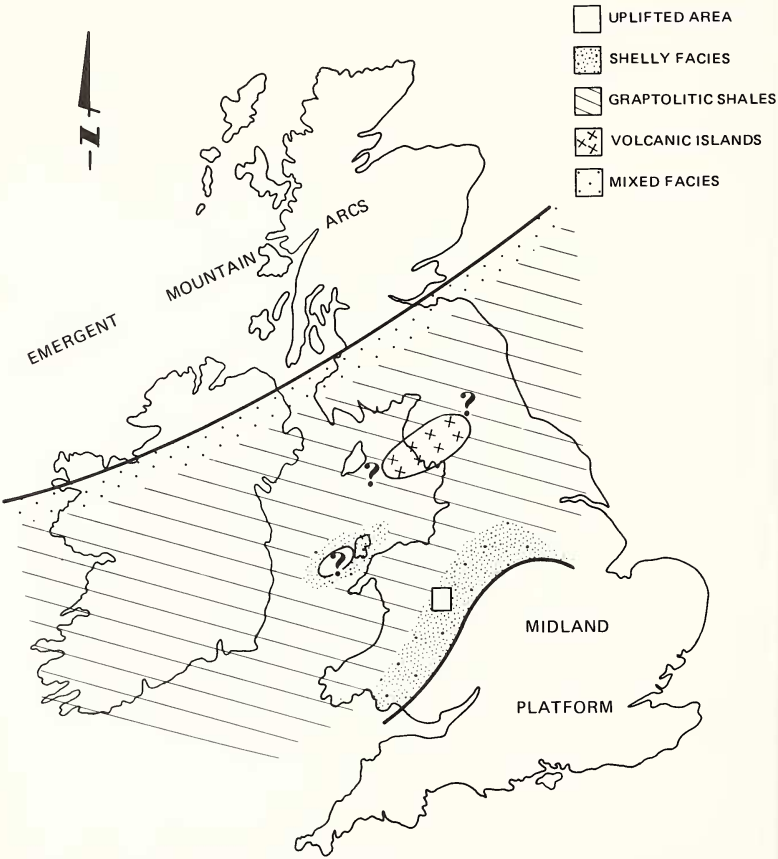
PROVENANCE OF THE REWORKED MATERIAL

The Tremadoc and Arenig/Llanvirn acritarchs encountered in the Caradoc type section are extremely well preserved suggesting that individuals were transported only short distances and underwent rapid reburial. Possible source rocks must therefore have been located close to the site of redeposition. It is unlikely that the reworked material was derived from the west since this was itself an area of deposition in Caradoc time. To the east and south, the Midland Platform formed a stable block during the Palaeozoic (text-fig. 6); Tremadoc rocks are widespread over this platform although Arenig/Llanvirn strata are practically unknown (Richardson and Rasul 1978, p. 37). To the south-east of Shropshire, probably close to the ancient margin of the Midland Platform, great thicknesses of Tremadoc sediments exist. Rocks of Arenig/Llanvirn age were possibly deposited in such peripheral areas but no traces have yet been found. Acritarch bearing Tremadoc and Arenig/Llanvirn strata are known from North Wales (Booth 1979; author's own unpublished data) and from the north of England (Booth 1979; Downie and Soper 1972), but the distances involved here are considerable and a closer source is considered more likely. No sedimentological evidence exists to indicate the direction of transport, but it appears probable that the reworked acritarchs were derived from the Midland Platform to the east or south-east. This is consistent with the available information on early Caradoc palaeocurrents (Williams 1969, p. 259, fig. 8).

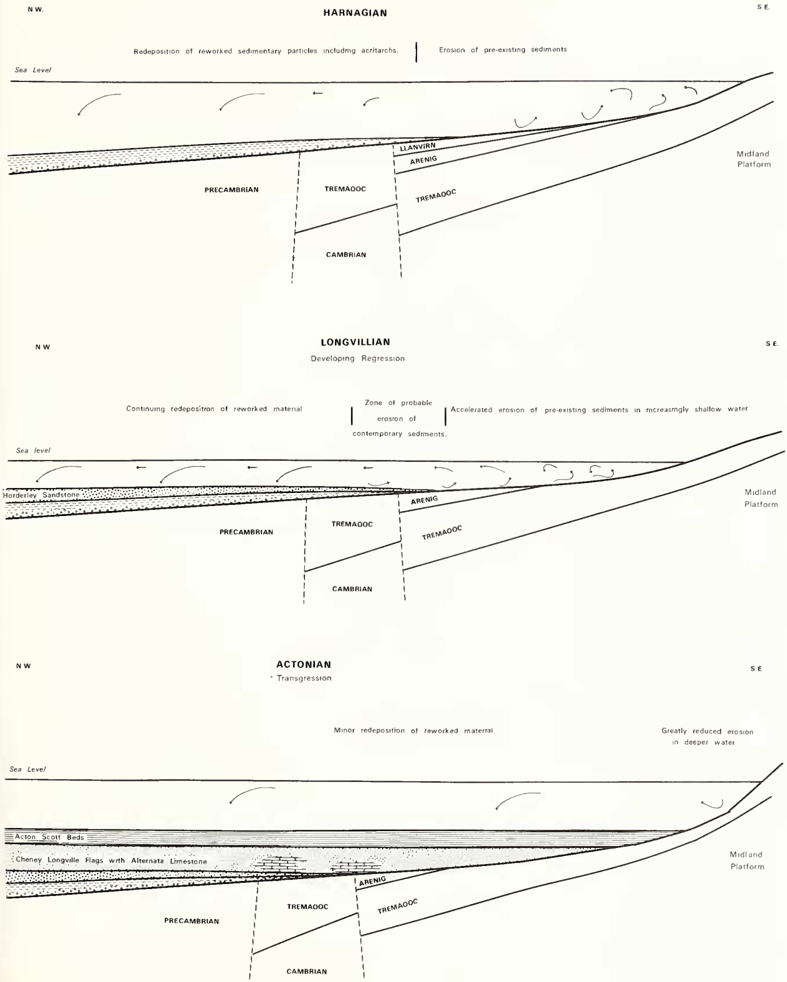
MECHANISM OF REWORKING

A widely accepted explanation of the mechanism for reworking of palynomorphs is that they were eroded and transported while encapsulated within particles of pre-existing sediments and so were protected from damage. If such recycled rock particles are present in a sediment they should be visible under microscopic examination (Richardson and Rasul 1978, p. 37). In the Onny Valley, lithologically diverse sediments such as the Harnage Shales, Horderley Sandstone, and Alternata Limestone all contain numerous reworked acritarchs. Thin-sections of samples from these formations were prepared and examined to see if such lithoclasts could be recognized but none was observed, the sediments presenting a more or less uniformly fine-grained appearance; the dimensions of sediment grains are between 5 and 100 μm with the vast majority being between 30 and 60 μm. Thus the grains are at most only slightly larger than reworked acritarchs recovered from the same samples. In addition, although no acritarchs were recognized in thin section, the sediments are clearly organic-rich and the abundant organic matter visible is trapped in the interstices. These factors make it unlikely that acritarchs were reworked in an encapsulated state, the evidence suggesting rather that they were eroded and redeposited as discrete sedimentary particles. This hypothesis is supported by the distribution pattern of the reworking which is unaffected by changes in the type of sediment being deposited (text-fig. 5). Similar reworked acritarchs are found in comparable numbers in sandstones, limestones, and flaggy micaceous siltstones. This alone suggests that the acritarchs were being introduced into the sediment/water-body system independently of the non-organic sediment particles.

If it is true that the reworked acritarchs were transported as individual particles then further conclusions can be drawn. Considering the excellent state of preservation of most reworked specimens, it is probable that dissolution of the parent rock was both easy and rapid. Since an indurated sediment would resist erosion, the Tremadoc and Arenig/Llanvirn rocks being eroded were probably at most only partly lithified. The retention of the most delicate morphological features on many reworked specimens suggests that erosion and transport were not only rapid but did not take place in a sub-aerial environment. Structures such as fine distal terminations of processes in



TEXT-FIG. 6. A suggested palaeogeographic reconstruction of the British Isles during Caradoc time (simplified, after Williams 1969).



TEXT-FIG. 7. Hypothetical diagrammatic cross-section through southern Shropshire in Caradoc time showing the postulated sequence of events. The Caradoc succession is simplified for the sake of clarity.

Vulcanisphaera cirrita (Pl. 16, fig. 1) and the delicate membranes of *Marrocanium simplex* (Pl. 17, fig. 1) would have been unlikely to survive long in turbulent conditions without the protection provided by encapsulation. Even if mechanical damage had been avoided, such features would have suffered rapid oxidation and disintegration. It is therefore postulated that erosion and redeposition of these pre-existing rocks took place in a shallow marine environment; wave and current action are considered the most likely agents for eroding and dispersing the unconsolidated sediments involved. Under these circumstances the enclosed acritarchs would be released directly into the sea, affording them the means both of protection and rapid dispersal and reburial (text-fig. 7). This agrees with the limited sedimentological evidence available which suggests that the Caradoc rocks were deposited in a shallow marine environment, possibly with off-shore barriers but with no estuaries present to have provided a potential source of reworked acritarchs from aerially exposed sediments (Hurst 1979*a*, p. 36). Hurst (op. cit., 1979*b*) has shown that in the Onny Valley the sequence from the upper part of the Horderley Sandstone to the basal Acton Scott Beds represents a regressive phase, and that the deposits of this interval were greatly affected by storm surge activity. The shallowing of the water body would have led to an increasingly high-energy regime, while individual surges would have resulted in mass sediment movement with rapid redeposition on the cessation of these geologically ephemeral events (text-fig. 7). Text-fig. 5 shows that the high-energy environment which resulted in the deposition of the upper Horderley Sandstone, Alternata Limestone, and Cheney Longville Flags, coincided with the period of greatest acritarch reworking. Above the base of the Actonian the percentage of reworked acritarchs is drastically reduced and it was at this time that storm swells ceased to exert any significant effect (Hurst 1979*b*, p. 196, Table 1). Unfortunately Hurst's studies do not extend down into the Soudleyan so it is uncertain how close the correlation is between the increasing energy levels and the first appearance of high levels of reworking. None the less there is clearly a link between the high-energy regime and abundant reworking, supporting the view that unlithified Tremadoc and Arenig/Llanvirn sediments were being eroded in a shallow marine environment.

Much has been written in recent years on the effects of storm surges on contemporaneous marine sediments (Brenner and Davis 1973; Reineck and Singh 1972, 1973), but there appear to be few data available on the effects of such events on soft pre-existing sediments at the water/substrate interface. Although little consideration has been given in the literature to the possibility of reworking from such sediments, the situation visualized here is not unique. For example, Quaternary clays in the Moray Firth, Scotland, contain extensive assemblages of reworked late Jurassic and early Cretaceous microfossils, particularly organic-walled microplankton (Owens and Marshall, 1978, pp. 24–26). This unoxidized material is well preserved and is clearly derived from unconsolidated Jurassic and Cretaceous shales and clays upon which the Quaternary rests in this area (Dr. R. Harland, pers. comm.). The physical state of these Mesozoic sediments suggests that reworking within lithic clasts would have been unlikely and redeposition of the microfossils as discrete particles is considered probable.

CONCLUSIONS

The type Caradoc rocks of Shropshire yield abundant acritarch assemblages which contain Caradoc species admixed with reworked Tremadoc and Arenig/Llanvirn taxa.

The vertical distribution of reworked forms reveals essentially an inverted stratigraphy with Arenig/Llanvirn acritarchs predominating in the lower horizons while the older Tremadoc species become the most abundant forms in the middle part of the sequence.

The lack of visible lithoclasts in thin sections of these rocks suggests that the microfossils were introduced into the sediment body as individuals and were not encapsulated in redeposited fragments of pre-existing rocks; this is substantiated by the fact that the presence and abundance of reworked acritarchs appears to be entirely independent of lithotype.

The excellent state of preservation of the reworked acritarchs indicates that they underwent little transportation before reburial. It also suggests that the parent sediments were relatively unconsolidated and that their erosion was caused by marine action in a shallow-water environment.

The high percentages of reworking in the middle part of the section are partly related to the increasing erosion of particularly acritarch-rich Tremadoc rocks. In addition, this sequence represents a regressive phase with storm surges having profound effects on the shallowing water body. Such high-energy events would have greatly increased the erosion rate of the unlithified sediments exposed at the sea bed. A state of continuous low-level erosion and acritarch reworking is envisaged, punctuated by periodic intense turbidity associated with an upsurge in the rate of release of pre-existing microfossils.

Acknowledgements. I am most grateful to Professor C. Downie for his encouragement during this work and for his advice and constructive comments. I thank Dr. G. A. Booth for access to his unpublished information and for much useful and stimulating discussion. My thanks also go to Dr. B. Owens, Dr. W. H. C. Ramsbottom, and Dr. W. A. M. Jenkins who read the manuscript and suggested improvements.

REFERENCES

BOOTH, G. A. 1979. Lower Ordovician acritarchs from successions in England and North Wales. University of Sheffield, unpublished Ph.D. thesis. 383 pp.

BRENNER, R. L. and DAVIES, D. K. 1973. Storm generated coquinoid sandstones: genesis of high-energy marine sediments from the Upper Jurassic of Wyoming and Montana. *Bull. geol. Soc. Am.* **84,** 1685–1698.

BURMANN, G. 1968. Diacrodien aus dem unteren Ordovizium. *Paläont. Abh.* B, **2,** 639–652.

—— 1970. Weitere organische Mikrofossilien aus dem unteren Ordovizium. Ibid. 3, 289–347.

COMBAZ, A. 1967. Un microbios du Trémadocien dans un sondage d'Hassi-Massaoud. *Act. Soc. linn. Bordeaux*, **B,** 104, 1–26.

CRAMER, F. H., ALLAM, B., KANES, W. H. and DIEZ, M. d. C. R. 1974. Upper Arenigian to Lower Llanvirnian acritarchs from the subsurface of the Tadla Basin of Morocco. *Palaeontographica*, B, **145,** 182–190.

—— and DIEZ, M. d. C. R. 1976. Seven new Late Arenigian species of the Acritarch Genus *Coryphidium* VAVRDOVÁ, 1972. *Paläont. Z.* **50,** 201–208.

—— —— 1977. Late Arenigian (Ordovician) acritarchs from Cis-Saharan Morocco. *Micropaleontology*, **23,** 339–360.

—— KANES, W. H., DIEZ, M. d. C. R. and CHRISTOPHER, R. A. 1974. Early Ordovician Acritarchs from the Tadla Basin of Morocco. *Palaeontographica*, B, **146,** 57–64.

DEAN, W. T. and MARTIN, F. 1978. Lower Ordovician acritarchs and Trilobites from Bell Island, Eastern Newfoundland. *Bull. geol. Surv. Can.* **284,** 1–35.

DEFLANDRE, G. 1937. Microfossils des silex crétacés, 11. Flagelles incertae sedis. Hystrichospaeridées. Sarcodinés. Organismes divers. *Annls. Paléont.* **26,** 51–103.

—— and DEFLANDRE-RIGAUD, M. 1961. Nomenclature et systématique des Hystrichosphères (s.l.) Observations et rectifications. *Lab. Micropaleont. E.P.H.E. Inst. Paleontol. Mus. Paris*, Multicop. 14 pp.

DEUNFF, J. 1961. Un microplancton à Hystrichospheres dans le Tremadoc du Sahara. *Revue Micropaléont.* **4,** 37–52.

—— and EVITT, W. R. 1968. *Tunisphaeridium*: A new acritarch genus from the Silurian and Devonian. *Standford Univ. Publs. Geol. Sci.* **12,** 1–13.

—— GÓRKA, H. and RAUSCHER, R. 1974. Observations nouvelles et précisions sur les Acritarches a large ouverture polaire du Paleozoique inférieur. *Geobios*, **7,** 5–18.

DOWNIE, C. 1958. An assemblage of microplankton from the Shineton Shales (Tremadocian). *Proc. Yorks. geol. Soc.* **31,** 331–349.

—— EVITT, W. R. and SARJEANT, W. A. S. 1963. Dinoflagellates, Hystrichospheres and the classification of the acritarchs. *Stanford Univ. Publs. Geol. Sci.* **7,** 2–16.

—— and SARJEANT, W. A. S. 1963. On the interpretation and status of some Hystrichosphere genera. *Palaeontology*, **6,** 83–96.

—— and SOPER, N. J. 1972. Age of the Eycott Volcanic Group and its conformable relationship to the Skiddaw Slates in the English Lake District. *Geol. Mag.* **109,** 259–268.

EARP, J. R. and HAINES, B. A. 1971. British Regional Geology: The Welsh Borderland. *Inst. Geol. Sci.* 118 pp. pub. H.M.S.O.

EISENACK, A. 1955. Chitinozoen, Hystrichosphären und andere mikrofossilien aus dem *Beyrichia*-Kalk. *Senckenberg. leth.* **36,** 157–188.

—— CRAMER, F. H. and DIEZ, M. d. C. R. 1976. *Katalog der fossilen Dinoflagellaten, Hystrichosphären und verwandten Mikrofossilien*, **4,** *Acritarcha part 2*, Stuttgart. 863 pp.

EVITT, W. R. 1963. A discussion and proposals concerning fossil dinoflagellates, hystrichospheres and acritarchs. *Proc. natn. Acad. Sci. U.S.A.* **49** (2), 158–164, 298–302.

FUNKHOUSER, J. W. 1969. Factors that affect sample reliability. *In* TSCHUDY, R. H. and SCOTT, R. A. (ed.). *Aspects of Palynology*, John Wiley and Sons. pp. 97–102.

GÓRKA, H. 1967. Quelques nouveaux acritarches des silexites du Trémadocien supérieur de la région de Kielce (Montagne de Ste Croix, Pologne). *Cahiers de Micropaleont. Series 1, 6, Arch. orig. Centre Documen. C.N.R.S.* **441,** 1–8.

HURST, J. M. 1979*a*. The environment of deposition of the Caradoc Alternata Limestones and contiguous deposits of Salop. *Geol. J.* **14,** 15–40.

—— 1979*b*. Evolution, succession and replacement in the type Upper Caradoc (Ordovician) benthic faunas of England. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **27,** 189–246.

—— 1979*c*. The stratigraphy and brachiopods of the upper part of the type Caradoc of South Salop. *Bull. Br. Mus. nat. Hist.* (*Geol.*), **32,** (4), 183–304.

JENKINS, W. A. M. 1967. Ordovician chitinozoa from Shropshire. *Palaeontology*, **10,** 436–488.

LAPWORTH, C. 1916. *In* Palaeontological Work, *summ. progr. Geol. Surv. Gt. Britain* 1915, 36–38.

LOEBLICH, A. R. JR. and TAPPAN, H. 1969. Acritarch excystment and surface ultrastructure with descriptions of some Ordovician taxa. *Rev. Esp. Micropaleontol.* **1,** 45–57.

—— —— 1976. Some new and revised organic-walled phytoplankton microfossil genera. *J. Paleont.* **50,** 301–308.

—— —— 1978. Some Middle and Late Ordovician microphytoplankton from central North America. Ibid. **52,** 1233–1287.

MARTIN, F. 1966. Les acritarches de Sart-Bernard, (Ordovicien-belge). *Bull. Soc. belge Géol. Paléont. Hydrol.* **74** (for 1965), 423–444.

—— 1969. Les acritarches de l'Ordovicien et du Silurien belges. Détermination et valeur stratigraphique. *Mém. Inst. r. Sci. nat. Belg.* **160** (for 1968), 175 pp.

—— 1973. Les acritarches de l'Ordovicien inferieur de la Montagne Noire (Herault, France). *Bull. Inst. r. Sci. nat. Belg.* **48** (for 1972), 1–61.

—— 1977. Acritarches du Cambro-Ordovicien du Massif du Brabant, Belgique. Ibid. **51** (for 1975), 1–28.

—— MICHOT, P. and VANGUESTAINE, M. 1970. Le Flysch Caradocien d'Ombret. *Annls. Soc. géol. Belge.* **93,** 337–350.

MURCHISON, R. I. 1839. The Silurian System. Murray, London (2 vols.). 768 pp.

OWENS, B. and MARSHALL, J. 1978. Micropalaeontological biostratigraphy of samples from around the coasts of Scotland. *Rep. Inst. Geol. Sci.* **78/20.** 35 pp.

PARIS, F. and DEUNFF, J. 1970. Le paleoplancton Llanvirnien de la Roche-au-Merle, (Commune de Vieux-Vy-Sur-Couesnon, Ille-et-Vi-laine). *Bull. Soc. géol. minér. Bretagne*, C, **2,** 25–43.

RASUL, S. M. 1974. The Lower Palaeozoic acritarchs *Priscogalea* and *Cymatiogalea*. *Palaeontology*, **17,** 41–63.

—— 1976. New species of the genus *Vulcanisphaera* (Acritarcha) from the Tremadocian of England. *Micropaleontology*, **22,** 479–484.

—— 1979. Acritarch zonation of the Tremadoc series of the Shineton Shales, Wrekin, Shropshire, England. *Palynology*, **3,** 53–72.

—— and DOWNIE, C. 1974. The stratigraphic distribution of Tremadoc acritarchs in the Shineton Shales succession, Shropshire, England. *Rev. Palaeobot. Palynol.* **18,** 1–19.

RAUSCHER, R. 1974. Recherches Micropaléontologiques et Stratigraphiques dans l'Ordovicien et le Silurien en France. *Mem. Sci. geol. Univ. Louis Pasteur Strasbourg, Inst. Geol.* **38** (for 1973), 209 pp.

REINECK, H. E. and SINGH, I. B. 1972. Genesis of laminated sand and graded rhythmites in storm-sand layers of shelf mud. *Sedimentology*, **18,** 123–128.

—— —— 1973. *Depositional sedimentary environments-*. Springer-Verlag, Berlin. 439 pp.

RICHARDSON, J. B. and RASUL, S. M. 1978. Palynomorphs in Lower Devonian sediments from the Apley Barn borehole, Southern England. *Pollen, Spores*, **20,** 423–462.

—— —— 1979. Palynological evidence for the age and provenance of the Lower Old Red Sandstone from the Apley Barn Borehole, Witney, Oxfordshire. *Proc. Geol. Ass.* **90,** 27–42.

STAPLIN, F. L. 1961. Reef-controlled distribution of Devonian microplankton in Alberta. *Palaeontology*, **4,** 392–424.

STAPLIN, F. L., JANSONIUS, J. and POCOCK, S. A. J. 1965. Evaluation of some acritarchous hystrichosphere genera. *Neues Jb. Geol. Palaont. Abh.* **123,** 167–201.

TIMOFEEV, B. V. 1958. Uber das Alter Sachsischer Grauwacken Mikropalaophytologische Untersuchungen von Proben aus der Weesensteiner und-Lausitzer Grauwacke. *Geologie*, **7,** 826–845.

—— 1959. Drevneyshaya flora Prebaltiki; i ee stratigraficheskoe znachenie. (The ancient flora of the Prebaltic and its stratigraphic significance.) *Trudy vses. neft. nauchno-issled. geol.-razv. Inst.* **129.** 319 pp. [In Russian.]

—— 1966. Mikropaleofitologicheskoe isseldovanie drevnikh svit. (Micropalaeophytological research into ancient strata). *Akad. Nauk. SSSR Lab. Geol. Dokembriya.* 147 pp. [In Russian.]

TURNER, R. E. and WADGE, A. J. 1979. Acritarch dating of Arenig volcanism in the Lake District. *Proc. Yorks. geol. Soc.* **42,** 405–414.

VANGUESTAINE, M. 1978. Donnees palynologiques nouvelles dans l'Ordovicien inferieur du bassin de la Senne, Massif du Brabant, Belgique. *Annls. Soc. géol. Belg.* **100,** 193–198.

VAVRDOVÁ, M. 1966. Palaeozoic microplankton from Central Bohemia. *Cas. Miner. Geol.* **11,** 409–414.

—— 1972. Acritarchs from Klabava Shales (Arenig). *Vest. ústred. Úst. geol.* **47,** 79–86.

—— 1973. New acritarchs from Bohemian Arenig (Ordovician). Ibid. **48,** 285–289.

—— 1976. Excystment mechanisms of early Palaeozoic acritarchs. *Cas. Miner. Geol.* **21,** 55–64.

—— 1977. Acritarchs from the Sarka formation (Llanvirnian). *Vest. ústred. Úst. geol.* **52,** 109–118.

WICANDER, E. R. 1974. Upper Devonian–Lower Mississippian acritarchs and Prasinophycean algae from Ohio, U.S.A. *Palaeontographica*, B, **148,** 9–43.

WILLIAMS, A. 1969. Ordovician of British Isles. *In* MARSHALL KAY (ed.), *North Atlantic—Geology and Continental Drift*, pp. 236–264.

WILSON, L. R. 1964. Recycling, stratigraphic leakage and faulty techniques in palynology. *Grana Palynol.* **5,** 425–436.

R. E. TURNER

Amoco Canada Petroleum Company Limited
Amoco Canada Building
444 Seventh Avenue S.W.
Calgary, Alberta T2P OY2
Canada

Typescript received 20 March 1980

Revised typescript received 12 November 1980